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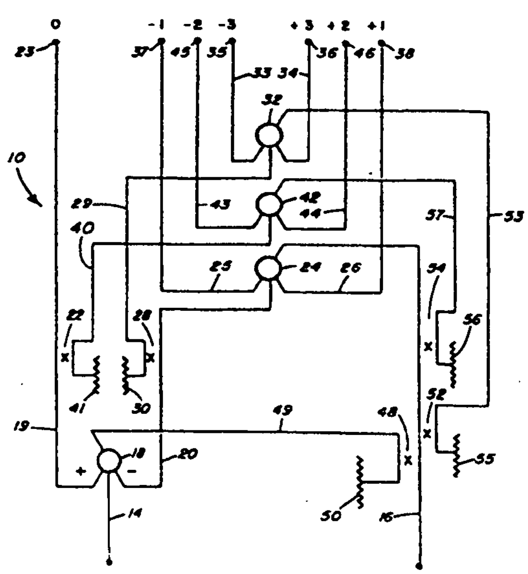
(54) Beam forming network for a butler matrix fed circular array.

(57) A beam forming network is described for generating a difference beam in a first direction with an omnidirectional sidelobe in other directions incorporating a plurality of hybrid circuits and a plurality of directional couplers coupled together. The invention overcomes the problem of requiring a more complex circuit for generating a difference beam with an omnidirectional sidelobe.



EP 0 227 910 A2

BEAM FORMING NETWORK FOR A BUTLER MATRIX FED CIRCULAR ARRAY

Background of the Invention

Field of the Invention:

This invention relates to antennas and more particularly to a beam forming network for an antenna.

Description of the Prior Art:

In an airborne collision avoidance system a sum and difference pattern is required for measuring the position of an aircraft within a 22.5° sector. Aircraft within a sector to be interrogated receives a P1 and P3 pulse of a greater amplitude than a P2 pulse which occurs in between the P1 and P3 pulses. The amplitude of the P2 pulse is attenuated in the desired sector by utilizing a difference pattern having its null pointed in the desired sector with the amplitude of the P2 pulse in all other directions exceeding the amplitude of the P1 and P3 pulses outside the desired interrogated sector.

In U.S. Patent 4,425,567, which issued on January 10, 1984, to C. P. Tresselt, a beam forming network is described in Figs. 4, 9 and 10 for forming sum and difference patterns with omnidirectional sidelobes.

In U.S. Patent 4,316,192, which issued on February 16, 1982, to J. H. Acoraci, a beam forming network is described in Fig. 7 for generating a sum and difference pattern. The beam forming network is shown coupled to a circular array antenna through a Butler matrix. Fig. 2 '192 shows that a difference pattern formed by the beam forming network of Fig. 7 is formed by subtracting a sum pattern from an omnidirectional pattern to form a cardioid which in turn was added to a difference pattern to form a difference pattern with omnidirectional sidelobes.

A publication by Sheleg entitled "A Matrix Fed Circular Array for Continuous Scanning", Proc. IEEE, November 1968, pp. 2016-2027 describes and shows in Fig. 2 a Butler matrix fed electronically scanned circular array.

It is therefore desirable to provide a simpler beam forming network for providing a difference pattern in one direction and an omnidirectional pattern in other directions.

It is further desirable to form a difference pattern in one direction and an omnidirectional pattern in other directions by summing a difference pattern and a 180° steered sum pattern.

Summary of the Invention

An apparatus and method is described for generating a difference beam in a first direction with an omnidirectional sidelobe in other directions comprising the steps of generating a difference beam having a maximum attenuation in a first and second direction substantially at 180° apart in a predetermined plane of radiation and generating a sum beam in said second direction having a predetermined amplitude whereby the maximum attenuation in the second direction is reduced.

Brief Description of the Drawing

Fig. 1 is a schematic diagram of one embodiment of the invention.

Fig. 2 is a block diagram of an antenna and feed network utilizing the embodiment of Fig. 1.

Fig. 3 is a graph of the sum pattern, minus the difference pattern, generated by the embodiment of Fig. 2.

Fig. 4 is a graph of the sum pattern, minus the sum pattern, which is steered 180° generated by the embodiment of Fig. 2.

Fig. 5 is a graph of the difference pattern generated by the embodiment of Fig. 2.

Fig. 6 is a graph of the combined difference and sum patterns generated by the embodiment of Fig. 2.

Fig. 7 is a plan view of one embodiment of hybrid 18 shown in Fig. 1.

Description of the Preferred Embodiment

Referring to Fig. 1, beam forming network 10 is shown for generating signals which may subsequently be coupled to antenna elements resulting in generating a difference beam in a first direction with an omnidirectional sidelobe in other directions. Beam forming network 10 may also generate a sum beam. Beam forming network 10 may receive microwave energy over line 14 for generating a sum beam pattern and may receive microwave energy over line 16 for generating a difference beam pattern with omnidirectional sidelobes. Line 14 is coupled to a first input of hybrid 18. When microwave energy is present on line 14, hybrid 18 functions to provide an in phase output on lines 19 and 20 with an amplitude attenuation of -3 dB on each line. Line 19 is coupled though directional coupler 22 to output terminal 23. Line 20 is coupled to the first input of hybrid 24. Hybrid 24 functions to receive microwave energy on line 20 and to provide an output on lines 25 and 26 which are in phase and attenuated by -3 dB. Lines 25 and 26 are coupled to output terminals 37 and 38, respectively. Line 20 is also coupled through directional coupler 28 which functions to couple a portion of the signal on line 20 with a predetermined amplitude such as -10.5 dB onto line 29. Directional coupler 28 may have line 29 terminated by resistor 30. Line 29 is coupled to a first input of hybrid 32. Hybrid 32 functions to receive microwave energy on line 29 and to provide an output on lines 33 and 34, which are in phase and attenuated by -3 dB. Lines 33 and 34 are coupled to output terminals 35 and 36.

Directional coupler 22 functions to couple a predetermined portion of microwave energy on line 19, such

as for example, -6.9 dB, to line 40. Directional coupler 22 may have one end of line 40 terminated by resistor 41. Line 40 is coupled to a first input of hybrid 42. Hybrid 42 functions to receive microwave energy on line 40 and to provide an output on lines 43 and 44, which are in phase and attenuated by -3 dB. Lines 43 and 44 are coupled to output terminals 45 and 46, respectively.

Line 16 is coupled to directional coupler 48, which functions to couple a portion of the microwave energy on line 16, such as an amplitude of -15.7 dB to line 49. Directional coupler 48 has one end of line 49 terminated by resistor 50. Line 49 is coupled to a second input of hybrid 18. Hybrid 18 functions to divide the microwave energy on line 49 to line 19, which is in phase and attenuated by -3 dB and to line 20, which is 180° out of phase and attenuated by -3 dB. Line 16 further passes through directional couplers 52 and 54 to a second input of hybrid 24. Directional coupler 52 functions to couple a portion of the microwave energy on line 16, such as -11.3 dB, onto line 53. Line 53 is coupled to a second input of hybrid 32. Hybrid 32 functions to divide the microwave energy on line 53 to line 33, which is in phase and attenuated by -3 dB and to line 34, which is 180° out of phase and attenuated by -3dB. Directional coupler 52 has resistor 55 coupled to one end of line 53 for terminating it. Directional coupler 54 has resistor 56 coupled to one end of line 57 for terminating it. Directional coupler 54 functions to couple a portion of the microwave energy on line 16 such as -7.4 dB to a second input of hybrid 42. Hybrid 42 functions to provide an output on line 43, which is in phase and attenuated by -3 dB and an output on line 44, which is 180° out of phase and attenuated by -3 dB.

Hybrid couplers 18, 24, 42, and 32 may be, for example, implemented with folded magic tees. Fig. 7 shows one embodiment of hybrid 18 with folded magic tees, wherein the first input, such as line 14 of hybrid 18, corresponds to the Σ input. The second input, such as line 49, corresponds

to the Δ input of a folded magic tee. The first output on line 19 corresponds to the Σ' output of a folded magic tee and the second output on line 20 corresponds to the Δ' output of a folded magic tee. An input signal to the Σ port of a folded magic tee provides a -90° phase delay with a -3 dB output at the Σ' port and at the Δ' port; and an input signal to the Δ port provides a -90° phase delay with a -3 dB output at the Σ' port and a -270° phase delay with a -3 dB output at the Δ' port. The -270° phase delay is provided by a folded line length in the folded magic tee. The folded magic tees are smaller in size than the circular 1.5 wavelength diameter rat race of the prior art from which the folded magic tees were derived. The folded magic tee may be constructed by providing a conductor or line length 135 of 90° of the design wavelength on printed circuit board 136 from the Σ port to the Σ' port, a 90° line length 137 from the Σ' port to the Δ port, a 270° line length 138 from the Δ port to the Δ' port, and a 90° line length 139 from the Δ' port to the Σ port.

Referring to Fig. 2, a block diagram is shown of beam forming network 10 coupled to a circular antenna array 60 through phase shifters 63-69 and Butler matrix 62. Output terminals 23, 37, 45, 35, 36, 46, and 38 of beam forming network 10 are coupled over lines 70 through 76, respectively, to an input of phase shifters 63 through 69. An output of phase shifters 63 through 69 is coupled over lines 77 through 83, respectively, to respective inputs of Butler matrix 62. An eighth input to Butler matrix 62 is terminated by resistor 85 coupled to line 84. Butler matrix 62 has eight outputs on lines 91 through 98, which are coupled to antenna elements 101 through 108, respectively, of circular antenna array 60. Antenna elements 101 through 108 may be evenly positioned about a circle having a center 130 and a diameter of 26.67 cm (10.5") shown by arrow 99 in Fig. 2. Butler matrix 62 functions to convert or transform the input signals on lines 77 through 84 which are suitable

for a linear antenna to a circular antenna array 60 to provide the same resultant antenna pattern.

The sum and difference patterns from beam forming network 10 may be steered by steering electronics 110, which has digital steering command input on line 111 and an output on line 112, which functions to control phase shifters 63 through 69. The terms sum pattern, difference pattern, sum beam and difference beam as used herein relate to antenna patterns suitable for use in monopulse radar direction finding.

The antenna patterns are radiated outward from circular antenna array 60. Reference line 131 is in the plane of circular antenna array 60 and passes through center 130. Reference line 132 is also in the plane of circular antenna array 60 and at an angle Ø shown by arrow 133 in Fig. 2 with respect to reference line 131. The position of reference line 131 may be considered at 0°. Thus, the angle Ø may represent an angle of radiation from circular antenna array 60.

In operation of beam forming network 10, shown in Figs. 1 and 2, when microwave energy is coupled to the sum terminal on line 14, the microwave energy is distributed to the output terminals 23, 37, 45, 35, 36, 46, and 38 having an amplitude and phase as shown in Table 1.

TABLE I

SUM PATTERN ILLUMINATION
INTO PHASE SHIFTERS

Terminal	Mode	Amplitude (dB)	Phase (Deg)
23	0	-4.002	0.0
37	-1	-6.426	0.0
45	-2	-12.921	0.0
35	-3	-16.521	0.0
36	+3	-16.521	0.0
46	+2	-12.921	0.0
38	+1	-6.426	0.0

The resulting antenna pattern radiated from circular antenna array 60, using the values shown in Table I, after appropriate phase shifters by phase shifters 63-69 is shown in Fig. 3. Phase shifts provided by phase shifters 63-69 function to provide focusing to the antenna pattern radiated from circular antenna array 60 and steering of the antenna pattern. The phases provided in Table II are suitable for coupling to a linear array of evenly spaced elements positioned transverse to the direction of radiation. In Fig. 3 the ordinate represents power in decibels and the abscissa represents polar angle in degrees. Curve 114 shows the sum beam and curves 115 through 118 show the sidelobe patterns.

When microwave energy is coupled to line 49, the microwave energy is distributed to microwave output terminals 23, 37, 45, 35, 36, 46 and 38 having an amplitude and phase as shown in Table II. The antenna pattern from circular antenna array 60, using the values shown in Table II, after appropriate phase shifts by phase shifters 63-69 is shown in Fig. 4.

TABLE II

SUM BEAM FILL IN ILLUMINATION

Terminal	Mode	Amplitude (dB)	Phase (Deg)
23	0	-4.002	0
37	-1	-6.426	180
45	-2	-12.921	0
35	-3	-16.521	180
36	+3	-16.521	180
46	+2	-12.921	0
38	+1	-6.426	180

In Fig. 4 the ordinate represents power in decibels and the abscissa represents polar angle in degrees. The sum

beam steered 180° is the result of coupling microwave energy from line 16 over line 49 to the second input of hybrid 18 as shown in Fig. 1. As shown in Fig. 4, curve 114 has been shifted 180° causing one half of curve 114 to appear on the left side of Fig. 4 and the other half of curve 114 to appear on the right side of Fig. 4 and curves 115 and 118 are joined together at 0°. Because of a reduction of power at the input of hybrid 18 due to coupler 48, curves 114, 115, and 118 are attenuated. Curves 116 and 117, shown in Fig. 3, are attenuated below -48 dB and therefore, are not shown in Fig. 4.

Fig. 5 is a graph of the difference pattern from circular antenna array 60 generated by beam forming network 10 shown in Figs. 1 and 2. Microwave energy coupled over line 16 and through couplers 52 and 54 to lines 53 and 57 and with no power coupled through coupler 48, is distributed to output terminals 23, 37, 45, 35, 36, 46 and 38 having an amplitude and phase as shown in Table III and provides a pattern after appropriate phase shifts by phase shifters 63-69 as shown in Fig. 5.

TABLE III

DIFFERENCE BEAM ILLUMINATION

WITH LINE 49 SEVERED

Terminal	Mode	Amplitude (dB)	Phase (Deg)
23	0	-19.702	0.0
37	-1	-3.282	180.0
45	-2	-12.067	180.0
35	-3	-13.376	180.0
36	+3	-15.628	0.0
46	+2	-9.806	0.0
38	+1	-5.535	0.0

In Fig. 5 the ordinate represents power in decibels and the abscissa represents polar angle in degrees. Curve 120 shows the difference pattern with curve portion 121 showing the desired deep attenuation notch of the difference pattern, while curve portions 122 and 123 show undesired deep attenuation 180° removed from curved portion 121.

Fig. 6 is a graph of the pattern from circular antenna array 60 generated by beam forming network 10 shown in Figs. 1 and 2 when microwave energy is coupled over lines 16, 49, 53 and 57. In Fig. 6 the ordinate represents power in decibels and the abscissa represents polar angle in degrees. Curve 125 shows an omnidirectional pattern with a difference pattern shown by curve portion 126. Fig. 6 is a composite or the addition of the curves shown in Figs. 4 and 5 resulting from microwave energy on lines 16, 49, 53 and 57 of beam forming network 10. As can be seen in Fig. 6, an omnidirectional pattern is generated in the region from -120° to -180° and from +120° to +180° having an amplitude and a range of -11 dB to -14 dB.

TABLE IV

Mode	Phase Shift	Phase Shift At 0° (Deg)	Phase Shift At 5° (Deg)
0	63	0	0
-1	64	26.418	31.418
-2	65	-30.941	-20.941
-3	66	-109.165	-94.165
+3	67	-109.165	-124.165
+2	68	-30.941	-40.941
+1	69	26.418	21.418

The pattern may be steered to a predetermined angle Ø by adjusting phase shifters 63-69. For example, to steer the pattern in Figs. 3-6 by 5° the following phase adjustments are made to phase shifters 63-69. Phase shifters 63-69 have the following phase shifts added to the phase shifts shown

in Table IV for $\emptyset$ equal to 0°: 0, 5, 10, 15, -15, -10, and -5 degrees, respectively. Table IV shows the phase shifts for $\emptyset$ equal to 5°.

The amplitude and phase of the signals on lines 77-83 going into the Butler matrix 62 to provide the filled in difference pattern shown in Fig. 6 is shown in Table V.

TABLE V

FILLED IN DIFFERENCE PATTERN – ILLUMINATION INTO BUTLER MATRIX

Line	Mode	Amplitude (dB)	Phase (Deg)
77	0	-19.702	0.000
78	-1	-3.282	-153.582
79	-2	-12.067	149.059
80	-3	-13.376	70.835
81	+3	-15.628	-109.165
82	+2	-9.806	-30.941
83	+1	-5.535	26.418

The invention describes an apparatus and method for generating a difference beam in a first direction with an omnidirectional sidelobe in other directions comprising the steps of generating a difference beam having maximum attenuation in the first and second directions substantially 180° apart in a predetermined plane of radiation and generating a sum beam in the second direction having a predetermined amplitude, whereby the maximum attenuation in the second direction is reduced to provide an omnidirectional pattern in directions away from the desired difference beam from 120° to 240°.

The invention claimed is:

CLAIMS:

1. Apparatus for generating a difference beam in a first direction with an omnidirectional sidelobe in other directions comprising:

means for generating a difference beam (52, 54, 24, 42, 32) having a maximum attenuation in a first and second direction substantially 180° apart in a predetermined plane of radiation, and characterized by

means for generating a sum beam (48, 18, 22, 28, 24, 42, 32) in said second direction having a predetermined amplitude whereby said maximum attenuation in said second direction is reduced.

2. The apparatus of claim 1 further characterized by said means for generating a difference beam (52, 54, 24, 42, 32) including a circular antenna array (60), a Butler matrix (62) coupled to said antenna array (60) for transforming input signals (23, 37, 45, 35, 36, 46, 38) for a linear antenna array to input signals for a circular antenna array, a plurality of phase shifters (63-69) coupled to said input signals (23, 37, 45, 35, 36, 46, 38) for phase shifting said input signals (23, 37, 45, 35, 36, 46, 38) prior to said Butler matrix (62), a beam forming network (10) coupled through said plurality of phase shifters (63-69) to said Butler matrix (62) for generating said input signals (23, 37, 45, 35, 36, 46, 38).

3. The apparatus of claim 2 further characterized by said beam forming network (10) including an input terminal (16), a plurality of couplers (52, 54) for coupling predetermined power levels of microwave energy with respect to said input terminal (16) at times said microwave energy is coupled to said input terminal (16), a plurality of hybrid circuits (32, 42, 24) coupled to the output of each said coupler (52, 54) for generating in phase and 180° out of phase first signals at predetermined power levels with respect to its input.

4. The apparatus of claim 3 further characterized by said means for generating a sum beam including a first coupler (48) coupled to said input terminal (16) for coupling a predetermined power level with respect to said input terminal (16) and having an ouptut (49) coupled to an input of a first hybrid circuit (18) for generating in phase and out of phase signals at predetermined power levels with respect to its input (49), each said in phase and out of phase signals coupled to at least one coupler (22, 28) to generate a plurality of in phase and out of phase second signals at predetermined power levels with respect to said input terminal (16) and means for coupling at least one of said second signals to one of said plurality of hybrid circuits (32, 42, 24).

5. A method for generating a difference beam in a first direction with an omnidirectional sidelobe in other directions comprising the step of:

generating a difference beam having maximum attenuation in a first and second direction substantially 180° apart in a predetermined plane of radiation, and characterized by the step of generating a sum beam in said second direction having a predetermined amplitude whereby said maximum attenuation in said second direction is reduced.

6. A beam forming network for generating a difference pattern with omnidirectional sidelobes characterized by:

an input terminal (16) coupled in series through first through third couplers (48, 52, 54) for coupling a predetermined amount of power with respect to the power at said input terminal (16) onto first through third lines (49, 53, 57),

said first through third lines (49, 53, 57) coupled to a first port of first through third hybrid circuits (18, 32, 42) respectively,

said input terminal (16) after coupling to said first through third couplers (48, 52, 54) coupled to a first port of a fourth hybrid circuit (24),

said first through fourth hybrid circuits (18, 32, 42, 24) each having first through fourth ports wherein an input signal at said first port (49, 53, 57, 16) provides an 180° out of phase signal at said second port (20, 34, 44, 26), no signal at said third port (14, 29, 40, 20) and an inphase signal at said fourth port (19, 33, 43, 25) and wherein an in phase signal at said third port (14, 29, 40, 20) provides no signal at said first port (49, 53, 57, 16) and an in phase signal at said second (20, 34, 44, 26) and fourth ports,

said fourth port (19) of said first hybrid circuit (18) coupled through a fourth coupler (22) to a first output terminal (23),

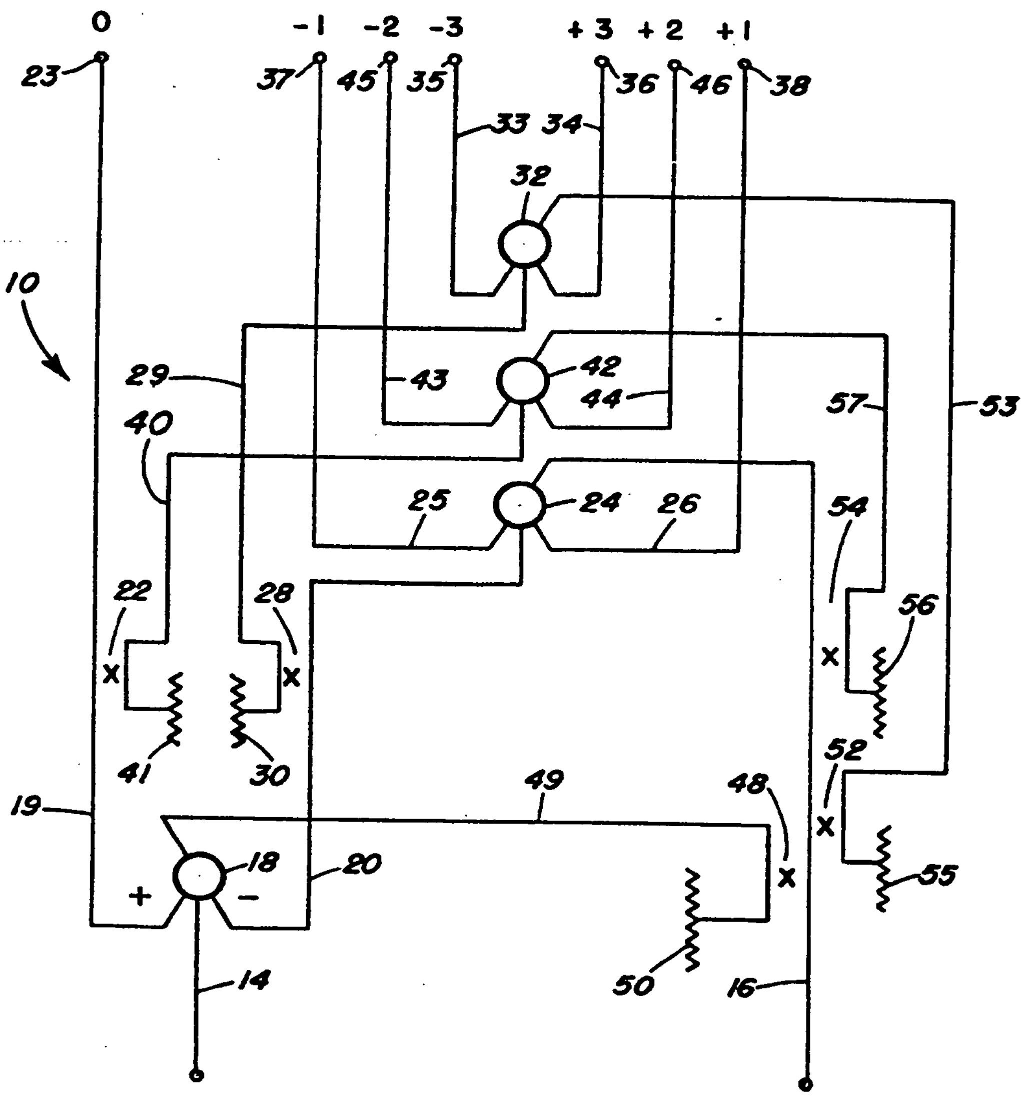
an output from said fourth coupler (22) coupled to said third port (40) of said third hybrid circuit (42),

said second port (20) of said first hybrid circuit (18) coupled through a fifth coupler (28) to said third port (20) of said fourth hybrid circuit (24),

an output from said fifth coupler (28) coupled to said third port (29) of said second hybrid circuit (32),

said fourth port (25, 43, 33) of said fourth, third and second hybrid circuit (24, 42, 32) coupled to a second (37), third (45) and fourth (35) output terminal respectively, and

said second port (34, 44, 26) of said second (32), third (42) and fourth (24) hybrid circuit coupled to a fifth (36), sixth (46) and seventh (38) output terminal, respectively.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+3
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+1
23
37
45
35
36
46
38
33
34
32
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29
42
43
44
57
53
40
25
24
26
54
22
28
56
x
x
x
41
30
52
19
49
48
18
20
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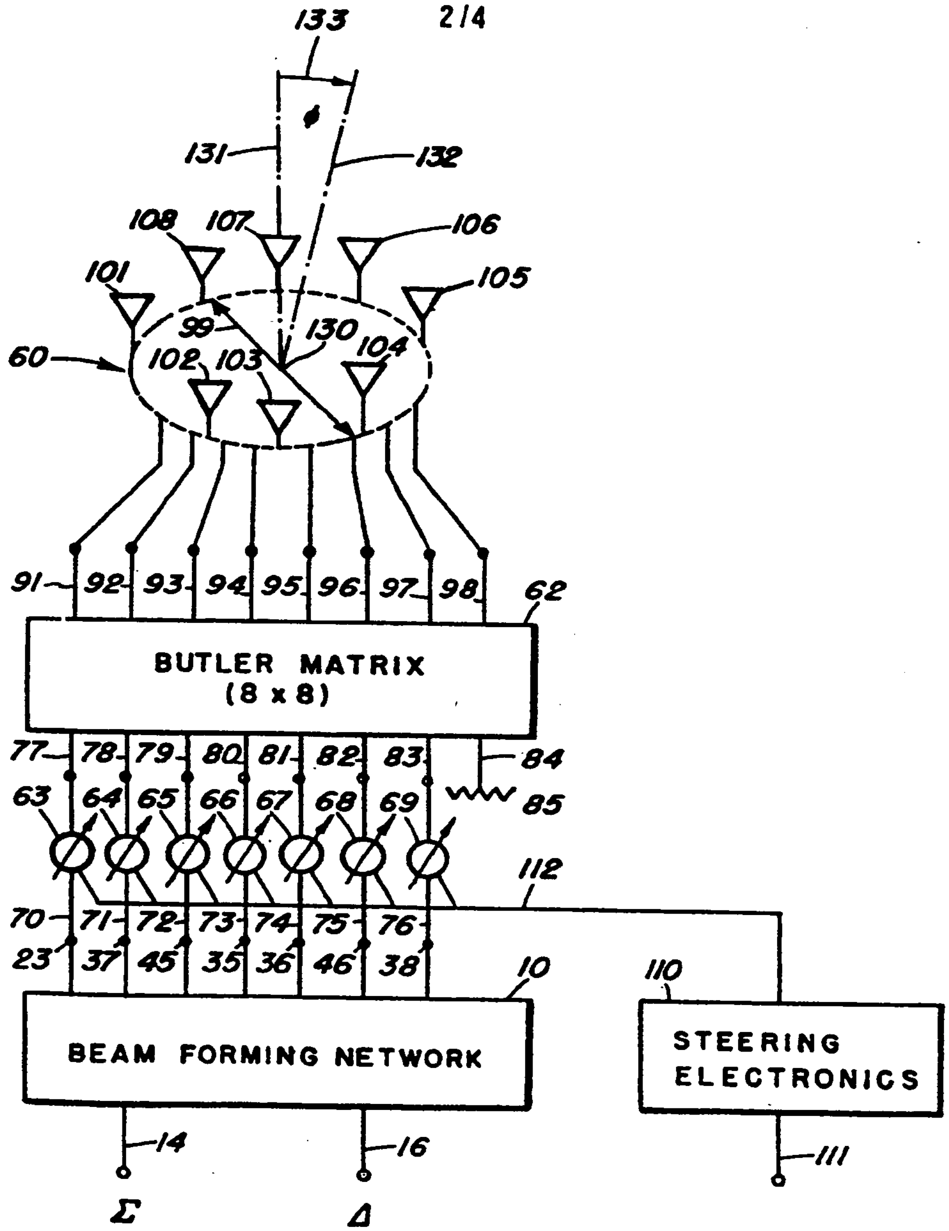
55
50
14
16

FIG. 1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ϕ
131
132
108
107
106
101
105
99
130
60
102
103
104
91
92
93
94
95
96
97
98
62
BUTLER MATRIX
(8 x 8)
77
78
79
80
81
82
83
84
63
64
65
66
67
68
69
85
112
70
71
72
73
74
75
76
23
37
45
35
36
46
38
10
110
BEAM FORMING NETWORK
STEERING
ELECTRONICS
14
16
111
Σ
Δ

FIG. 2

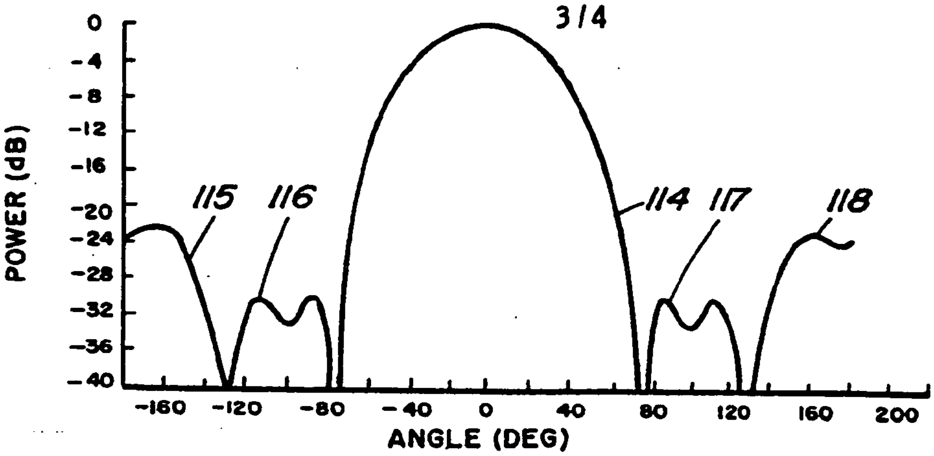


FIG. 3

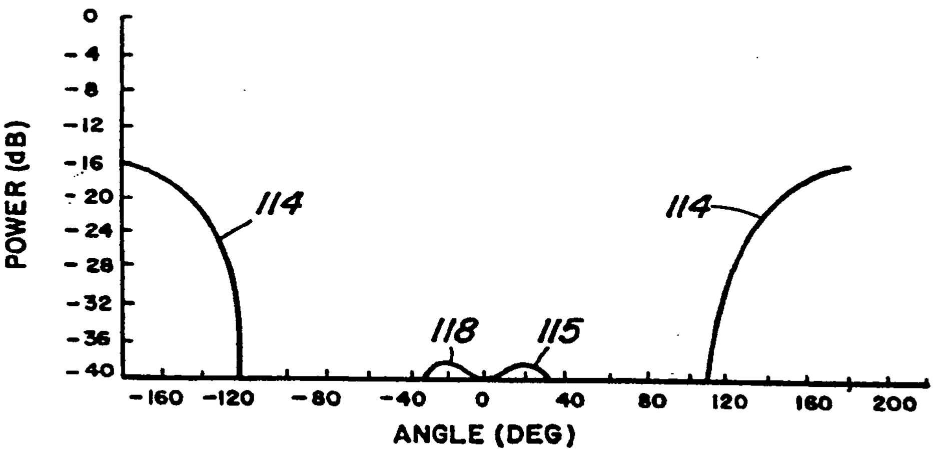


FIG. 4

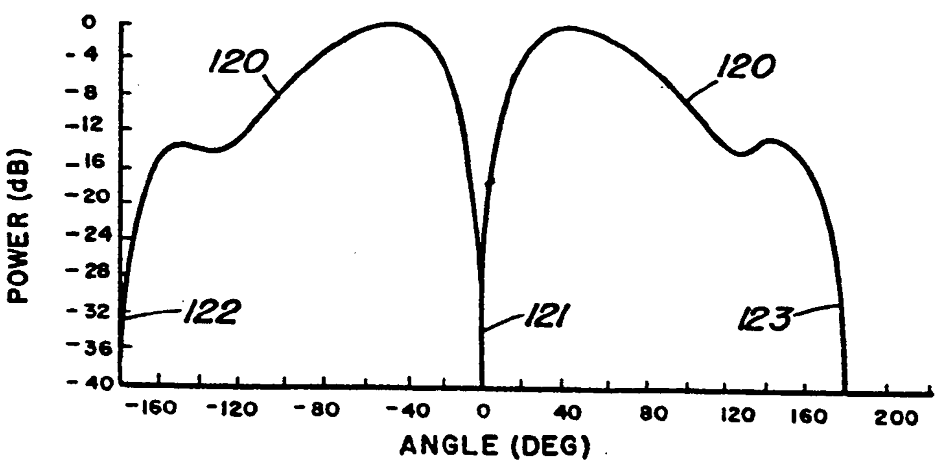
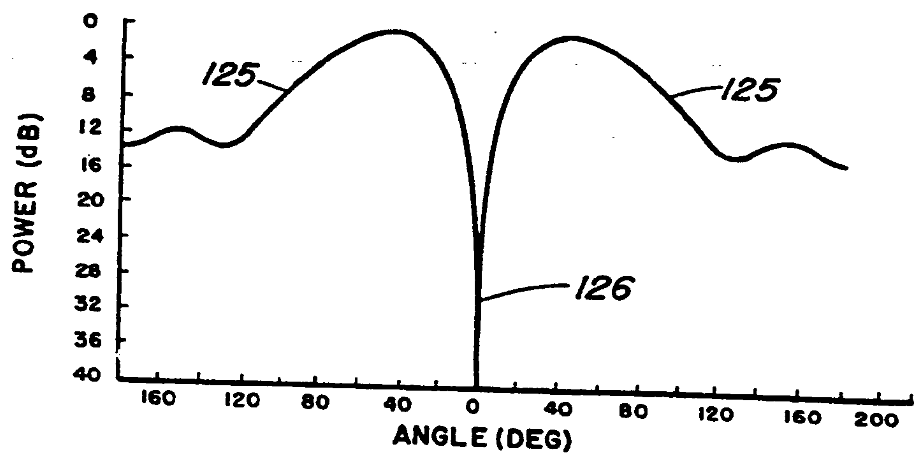


FIG. 5

FIG. 6


POWER (dB)
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4
8
12
16
20
24
28
32
36
40
125
125
126
160
120
80
40
0
40
80
120
160
200
ANGLE (DEG)

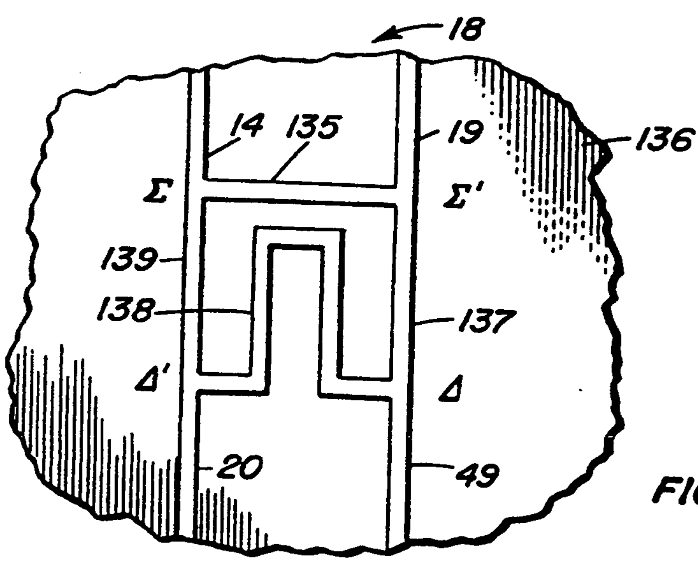
18
14
135
19
136
Σ
Σ'
139
138
137
Δ'
Δ
20
49

FIG. 7

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(54) **Beam forming network for a butler matrix fed circular array.**

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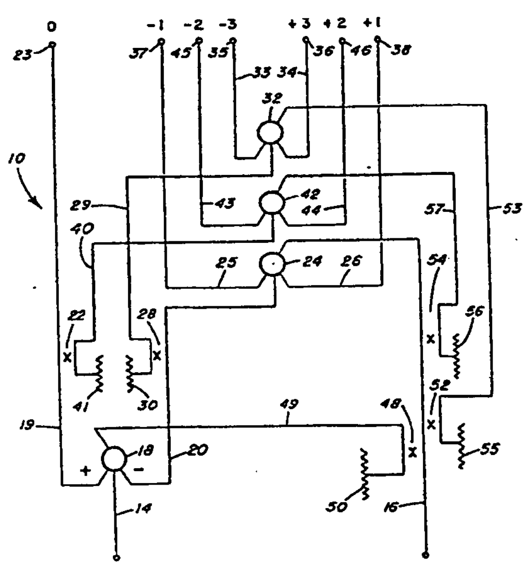

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European Patent Office

EUROPEAN SEARCH REPORT

0227910

Application number

EP 86 11 5004

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int. Cl 4)
A	PROCEEDINGS OF THE IEEE 1979 NATIONAL AEROSPACE AND ELECTRONICS CONFERENCE, NAECON 1979, Dayton, 15th-17th May 1979, vol. 1, pages 44-49, IEEE; J.A. ACORACI: "Small lightweight electronically steerable cylindrical antenna successfully utilized in an air traffic management system" * Figures 9-11; page 47, left-hand column, line 26 - page 48 *	1-6	H 01 Q 3/40 H 01 Q 25/02

A	US-A-4 196 436 (WESTERMANN) * Abstract; column 3, lines 13-55; figure 1 *	1,5	
	---		**TECHNICAL FIELDS SEARCHED (Int. Cl.4)**
A	US-A-3 713 167 (DAVID) * Figures 2,5-8b *	6	

A	US-A-4 101 892 (ALFORD) * Abstract; figure 11 *	6	H 01 Q G 01 S

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	09-09-1987	ANGRABEIT F.F.K.

CATEGORY OF CITED DOCUMENTS

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